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Conference Summary: 6^{th} International Conference on Hyperons, Charm, and Beauty Hadrons (BEACH04)

Joel N. Butler[a] *,

[a]Fermi National Accelerator Laboratory,
Wilson Hall, MS 122
P.O. Box 500,
Batavia, IL, USA 60510-0500

The 6^{th} International Conference on Hyperons, Charm, and Beauty Hadrons (BEACH04) treated us to a wonderful array of new results. Here I attempt to summarize the talks and discuss the conference highlights.

1. INTRODUCTION

The 6^{th} International Conference on Hyperons, Charm, and Beauty Hadrons (BEACH04), was held from June 28, 2004 to July 3, 2004, at the Illinois Institute of Technology, in Chicago. On behalf of all the participants, I'd like to thank the organizers for putting together an excellent conference with an outstanding physics program and a pleasant social program that encouraged informal interactions with colleagues on the important scientific issues that arose. During the conference, there were more than 80 presentations that I am charged to summarize. I want to thank the speakers for the outstanding quality of their talks and they and their collaborators for the very high quality research they are doing. The scope and depth makes the task of summarizing the conference very challenging and I apologize in advance for the omission of many important results.

1.1. Overview of the Conference

Many of the fundamental parameters and key phenomena of the Standard Model (SM) of particle physics are associated with the weak decays of heavy quarks. These include quark masses and mixing parameters. These "weak interaction" parameters, properties of the quarks, must be extracted from the decays of the hadrons into which the quarks are bound. The separation of the weak decay properties from the effects of the strong interaction in the non-perturbative regime is one of the great challenges of modern particle physics. Beyond this lie even more fundamental issues, such as why there are three generations, why the quarks have the pattern of masses that they do, and why the mixing angles have the particular values we observe. This is the "flavor problem," a problem so deep and mysterious that we often pretend it isn't there. More generally we want to know whether hidden within the uncertainties and ambiguities in our understanding, there is evidence for physics beyond the Standard Model that will help explain some of these mysteries. If there is one lesson to take away from this conference, it is that although we know a huge amount about the properties of heavy quarks and their decays, there is still a lot we don't know.

1.2. Observations on the Study of the Physics of Heavy Quarks

Professor Cabibbo in his introductory talk reminded us that, although in most heavy quark decays we are faced with the problem of disentangling the strong and weak interaction effects, nature has provided us with a small number of theoretically clean decays where this problem is almost completely avoided:

Golden channels : the ones whose interpreta-

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tion does not depend (much) on our imperfect understanding of hadronic structure. These lead to measurements of interesting physical quantities whose uncertainties are dominated by experimental measurement errors; and

Silver channels : the ones whose interpretation depends on an understanding of hadronic structure, but there is a good strategy, now most often provided by Lattice QCD, to compute directly what is needed.

Table 1 gives a list of these favored modes.

The key point is that we are extremely lucky to have these "theoretically clean" channels and should do the experiments to exploit them thoroughly! This implies continuing work in measurement of B decays and a new round of measurements in the very rare Kaon decays, $K_L^o \to \pi^o \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$.

It is worth noting that whether a particular decay can be called "theoretically clean" according to the definitions above depends both on the state of theory and also on the accuracy with which it can be measured experimentally and is subject to change over time.

Table 1
Theoretically Clean Channels for Heavy Quark Decay

Golden Channels
beta decay
$B^o \to \psi K_s$
some inclusive decays - see determination of V_{cb}
$K^+ \to \pi^+ \nu\bar{\nu}$
$K_L \to \pi^o \nu\bar{\nu}$
Silver Channels
ΔM_d (lattice measurement of $f_{B_d},\ B_{B_d}$)
ΔM_s (lattice measurement of $f_{B_s},\ B_{B_s}$)
ϵ_K

2. B PHYSICS, CURRENT EXPERIMENTS AND THEORY

B physics has progressed rapidly over the last few years, primarily due to the abundance of new results produced by the asymmetric B factories at SLAC and KEK. Michael Gronau reminded us of the need to keep working at improving and expanding these measurements to

- search for and study Direct CP violation;
- provide stronger constraints on the CKM angles α and γ; and
- look for conflicts between results and the CKM fits that could signify New Physics (NP) beyond the SM. Such measurements could help in the interpretation of new phenomena observed at the Tevatron or the LHC.

2.1. Status of Measurements of CKM Angles in B Decays

2.1.1. The CKM angle β

The CKM angle β has been measured in the "golden channel" $B^o \to \psi(\mu^+\mu^-)K_s(\pi^+\pi^-)$ at the B factories. Other measurements that also involve the quark-level process $b \to c\bar{c}s$ are $B^o \to \psi(2S)K_s, \chi_{c1}K_s, \eta_c K_s$, and $\psi K^*(K_s\pi^o)$ (and corresponding modes with K_L). These generally have much poorer statistical precision but, within uncertainties, agree with the main determination from $B^o \to \psi K_s$. The average of the "charmonium" results from the B Factories[1] are

$$\begin{aligned} \sin 2\beta &= 0.733 \pm 0.057 \pm 0.028 \text{ BELLE} \quad (1) \\ \sin 2\beta &= 0.741 \pm 0.067 \pm 0.033 \text{ BaBar} \end{aligned}$$

The overall world average, including earlier, lower precision results from CDF, ALEPH, and OPAL,[1] is

$$\sin 2\beta = 0.736 \pm 0.049 \quad (2)$$

This is very impressive and should be accorded the status of a "precision measurement."

It is worth noting that, from these measurements alone, the angle β is left with a four fold ambiguity.

It is also possible to measure $\sin 2\beta$ in decays proceeding by the quark level process $b \to c\bar{c}d$.

This is a CKM suppressed decay so these determinations also have poorer statistical precision than the "golden channel." These modes may suffer from Penguin pollution and in some cases involve vector-vector decays that present additional complications. While statistics are generally very poor, the measurements of $\sin 2\beta$ are compatible with the value obtained from the $b \to c\bar{c}s$ decays.

The decay $B^o \to \psi K^{*o}$, another "charmonium" type B decay, has both CP-even and CP-odd amplitudes and is therefore more difficult to study to extract the angle β. However, its study offers a bonus, since the interference between the CP-even and odd amplitudes provides a new interference term in the time dependent asymmetry[2]:

$$a(t) = P\cos\Delta mt + \sin\Delta mt(S\sin 2\beta + C\cos 2\beta) \quad (3)$$

where P, S, and C are related to the three transversity amplitudes A_o, $A_\perp$, $A_\|$ and their strong phases δ_o, $\delta_\perp$, and $\delta_\|$. The strong phases may be determined from the study of the decays $B^{o,+} \to \psi K^{*o,+}$. Then, we find that

$$C \propto \cos(\delta_\perp - \delta_\|) \text{ and } \cos(\delta_\perp - \delta_o) \quad (4)$$

The study shows a non-trivial strong phase,

$$\delta_\| - \delta_\perp = 0.597 \pm 0.077 \pm 0.017 \quad (5)$$

While the data are still statistically weak, they already begin to indicate that $\cos 2\beta > 0$ at 89% confidence level. More precise results will remove part of the ambiguity in the measurement of β.

There are several decays that measure $\sin 2\beta$ in $b \to s$ Penguin-dominated modes. Modes that have been studied are:

$$B^o \to \phi K_s, \eta' K_s, f_o(980)K_s, \pi^o K_s, K^+K^-K_s \quad (6)$$

A departure of the value of $\sin 2\beta$ determined from any of these from that obtained with ψK_s would indicate the presence of new physics. Data on all these modes suffer from low statistics but, within the statistics generally agree with $\sim$0.74, except for the decay $B^o \to \phi(K^+K^-)K_s$ [3],[4], where

$$\begin{aligned} \sin 2\beta &= -0.96 \pm 0.50^{+0.09}_{-0.11} \text{ (BELLE)} \quad (7) \\ \sin 2\beta &= 0.47 \pm 0.34^{+0.08}_{-0.06} \text{ (BaBar)}. \end{aligned}$$

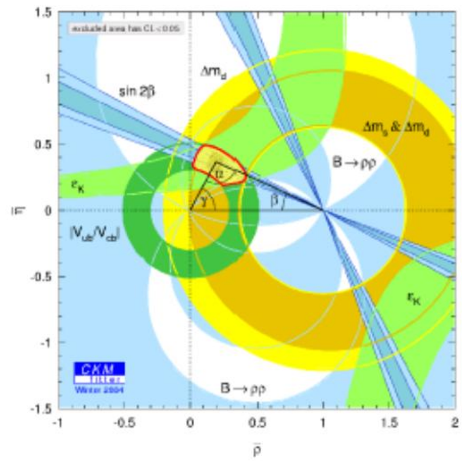

Figure 1. Current status of knowledge of the CKM triangle, shown on the $\rho - \eta$ plane

This mode has no tree contributions, which are assumed to be dominated by SM physics, and so is thought to be an excellent place to look for new physics that would appear in the loop contribution. Unfortunately, at this time the statistics are too low to draw a conclusion and we eagerly await more data.

Progress is also being made in the study of time-dependence of the decays $B^o \to K_s\pi^o$, previously thought to be unfeasible, and of $B^o \to K^*\gamma \to K_s\pi^o\gamma$.

These measurements clearly establish CP violation in the B-meson system. A new method has been developed to measure $\cos 2\beta$. All data are consistent with the CKM picture with the possible exception of the CP asymmetry in ϕK_s. The overall status of our knowledge of the ρ and η parameters of the CKM Matrix is shown in Fig. 1[6].

2.1.2. The CKM angle γ

Several methods have been proposed to measure γ in $B_{d,u}$ decays. These include

1. using the "mixing-induced asymmetry" in $B^o \to D^{(*)\pm}\pi^\mp$ to obtain $\sin(2\beta + \gamma)$, and using the precision measurement of $\sin\beta$ to extract γ;

2. $B^{\pm} \to DK^{\pm}$, where the D^o decays into a CP even or CP odd eigenstate are compared (The Gronau, London, Wyler method);

3. $B^{\pm} \to DK^{\pm}$ where the D^o decays into a doubly Cabibbo suppressed mode $D^o \to K^+\pi^-$ (Atwood, Dunietz, Soni method);

4. $B^o \to K\pi$; and

5. A comparison of the Dalitz plot of $D^o \to K_s\pi^+\pi^-$ in the decays $B^+ \to D^oK^+$ and $B^- \to D^oK^-$. A difference in two Dalitz plots provides a measure of γ.

These are accessible to e^+e^- B factories and hadron collider experiments. The fourth technique suffers from theory ambiguities. The fifth method, described below, has been introduced by BaBar and BELLE recently. A sixth method, to extract γ from the time-dependent asymmetry in the decay $B_s \to D_sK$ can only be carried out at hadron colliders.

The time-dependent analysis of the decay $B^o \to D^{(*)\pm}\pi^{\mp}$ involves the CKM phase 2β, through mixing, and the angle γ through $B^o \to D^{(*)+}\pi^-$ and measures

$$\sin(2\beta + \gamma) \tag{8}$$

The problems with this approach are that it depends on an unknown strong phase difference, δ, between the two B decay modes and the interference effect is small because the two interfering decays have vastly different amplitudes:

$$r^* = \frac{|A(\bar{B}^o \to D^{(*)-}\pi^+)|}{|A(\bar{B}^o \to D^{(*)+}\pi^-)|} = \frac{|V_{ub}^* V_{cd}|}{|V_{cb}V_{ud}^*|} \propto 0.02 \tag{9}$$

These are derived from $Br(\bar{B}^o \to D_s^{(*)\pm}\pi^{\mp})$ using SU(3).

The time-dependent decay rates are[7]

$$\begin{aligned} &P(B^o \to D^{(*)\mp}\pi^{\pm}) \\ &\quad \propto \quad 1 \pm \cos(\Delta m_d \Delta t) + (a \pm b \mp c)\sin(\Delta m_d \Delta t) \\ &P(\bar{B}^o \to D^{(*)\mp}\pi^{\pm}) \\ &\quad \propto \quad 1 \mp \cos(\Delta m_d \Delta t) - (a \mp b \pm c)\sin(\Delta m_d \Delta t) \\ &a = 2r\sin(2\beta+\gamma)\cos(\delta) \\ &b = 2r'\sin(2\beta+\gamma)\cos(\delta') \\ &c = 2\cos(2\beta+\gamma)(r\sin(\delta) - r'\sin(\delta')) \end{aligned} \tag{10}$$

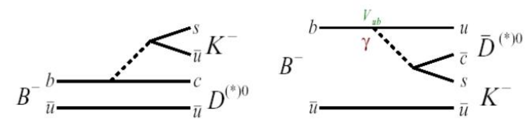

Figure 2. Two decay amplitudes for $B^- \to D^{*o}K^-$ whose interference can cause differences in the $D^o \to K_s\pi^+\pi^-$ Dalitz plot

The results may be used to extract a lower limit on $|\sin(2\beta+\gamma)|$ as a function of the value of r.

The latest method to be tried is to compare the Dalitz plot of the D^o from the decay $B^- \to D^{(*)o}K^-$ to its charge conjugate, where the $D^o(\bar{D}^o)$ decays to $K_s\pi^+\pi^-$ [8]. There are two decay amplitudes shown in Fig. 2. The CKM phase that appears is γ and there can be a relative strong phase between these two amplitudes. One can write

$$\begin{aligned} &\qquad B^+ \to \tilde{D}^oK^+ : \\ |\tilde{D}^o> &= |D^o> + r\exp^{i(\delta+\gamma)}|\bar{D}^o> \\ &\qquad B^- \to \tilde{D}^oK^- : \\ |\tilde{D}^o> &= |\bar{D}^o> + r\exp^{i(\delta-\gamma)}|D^o> \end{aligned} \tag{11}$$

One problem is that the $K_s\pi^+\pi^-$ decay of the D^o can receive contributions from many resonances. Using their full sample of 102,000 D^o decays, BELLE determines the resonant decomposition of the decay and uses the amplitudes in the fit along with the parameters r, δ and γ. The result is quoted as [10]

$$\begin{aligned} \gamma &= (77^{+17}_{-19})^o \quad 68\% \text{ CL} \\ \gamma &= (77^{+35}_{-38})^o \quad 95\% \text{ CL} \end{aligned} \tag{12}$$

or $26^o < \gamma < 126^o$ at the two standard deviation level [9]. It is worth noting that the error analysis is difficult.

2.1.3. The CKM angle α

The CKM angle α provides an important consistency check on the whole CKM picture of quark mixing. The mixing-induced time-dependent

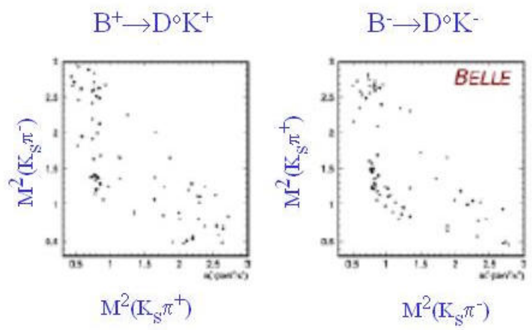

Figure 3. A comparison of the $K_s\pi^+\pi^-$ for (left) $B^+ \to D^o K^+$ and (right) $B^- \to D^o K^-$

asymmetry of the decay $B^o \to \pi^+\pi^-$ would measure α if the tree-amplitude were the only one present. However, the presence of Penguin amplitudes with different CKM phase disturbs this and leads to the possibility of "direct" as well as mixing-induced CP violation. This leads to an expression for the time-dependent asymmetry with both mixing-induced and direct CP violation:

$$Asym = A_{\pi\pi}\cos(\Delta m\Delta t) + S_{\pi\pi}\sin(\Delta m\Delta t) \quad (13)$$

It is the identification of $S_{\pi\pi}$ with the CKM quantity $\sin 2\alpha$ that is spoiled by the presence of the penguin processes.

The values obtained from this analysis by BELLE [11] are

$$\begin{aligned} A_{\pi\pi} &= 0.58 \pm 0.15 \text{ stat.} \pm 0.07 \text{ syst.} \quad (14)\\ S_{\pi\pi} &= -1.00 \pm 0.21 \text{ stat.} \pm 0.07 \text{ syst.} \end{aligned}$$

Based on this result, BELLE claims evidence for observation of CP violation in this decay, and in particular, evidence for direct CP violation.

The values obtained from this analysis by BaBar [12] are

$$\begin{aligned} A_{\pi\pi} &= 0.19 \pm 0.19 \text{ stat.} \pm 0.05 \text{ syst.} \quad (15)\\ S_{\pi\pi} &= -0.40 \pm 0.22 \text{ stat.} \pm 0.03 \text{ syst.} \end{aligned}$$

These are about 2σ different than BELLE's result. More data will be needed to clear this up.

It has been shown [13] that the "Penguin pollution" problem can be overcome by directly isolating the Penguin amplitude by comparing $B^o \to \pi^+\pi^-$, $B^o \to \pi^o\pi^o$, and $B^+ \to \pi^+\pi^o$ and their charge conjugates. The $B^o \to \pi^o\pi^o$ decay mode has now been observed with a branching fraction of $(1.9 \pm 0.5) \times 10^{-6}$. Even with this relatively large branching fraction, the efficiency for reconstructing the final state is low and it will be very hard to obtain good enough statistics to execute this method.

An alternative approach is to study the Dalitz plot for the decay $B^o \to \rho\pi \to \pi^+\pi^-\pi^o$. The isospin 3/2 amplitude is due only to the tree contribution and can be isolated and its time-dependent asymmetry gives a "pollution-free" measurement of α. Again, the statistics at current e^+e^- machines will be too low to make a good measurement. However, BaBar and BELLE have made progress with a simplified analysis using only $B^o \to \rho^\pm\pi^\mp$[14]. With some model-dependent assumptions, Gronau and Zupan[15] have been able to obtain the value $\alpha = 94^o \pm 19^o$.

Recently progress has been made in extracting α from the decay $B^o \to \rho^\pm\rho^\mp$[16]. Since this is a vector-vector decay mode, there are both CP even and CP odd components in its decay, which complicates the analysis greatly. This decay also potentially suffers from Penguin pollution. However, the limit on the decay mode $\rho^o\rho^o$, which is expected to be Penguin-dominated, when compared to the observed branching fractions for $B^+ \to \rho^+\rho^o$ and $B^o \to \rho^+\rho^-$, which are expected to be tree-dominated, demonstrates that the Penguin contribution is small. Moreover, a helicity analysis of the decays that have been observed indicate that the ρ's are predominantly longitudinally polarized[17]:

$$f_L = 0.98 - 0.99 \quad (16)$$

meaning that the decay is almost always into a CP-even final state. Taken together, this suggests that an analysis of the tagged, time-dependent asymmetry of $B^o \to \rho^\pm\rho^\mp$, described by

$$P^{long}_{q=\pm1} \propto [1 \mp C_L\cos(\Delta m\Delta t) \pm S_L\sin(\Delta m\Delta t)] (17)$$

should give a good constraint on α.

Possible problems with this analysis are

- non-resonant background in the Dalitz plot, $B^o \to \rho^+\pi^-\pi^o, \pi^+\pi^o\pi^-\pi^o$;

- the width of the charged ρ allows for an I=1 final state. The I=1 final state is normally dropped from the analysis because it is forbidden by Bose-Einstein statistics. However, since the ρ is broad, the two ρ mesons will not be created with the same mass so that B.E. statistics would not apply and an I=1 amplitude would be allowed[18]; and
- The Penguin amplitude is not zero and is only constrained to a certain level by the upper limit on the $\rho^o\rho^o$ branching fraction.

An analysis of the results of the $B^o \to \rho^\pm\rho^\mp$ results from BaBar by Grossman and Quinn[19] give $\alpha = 102^{+16}_{-12}\,(\text{stat.})^{+5}_{-4}\,(\text{syst.}) \pm 13(\text{Penguin})$ degrees. The last error is due to the uncertainty on the level of the Penguin contribution. Qualitatively, these analyses constrain α to between 60^o and 130^o at the 95% confidence level.

2.1.4. Summary on status of CKM angle measurements

Gronau provided a nice summary of the status of the CKM measurements. The measurement of $\sin 2\beta$ is an impressive achievement and has established CP violation in B decays. Unfortunately, no other measurement is as pure and easy as this one. Current constraints on the angles at 95% CL from the CKM fit are[20]:

$$\begin{aligned} 78^o &< \alpha < 122^o \\ 21^o &< \beta < 27^o \\ 38^o &< \gamma < 80^o \end{aligned} \tag{18}$$

The measurements of $B^o \to \pi^+\pi^-$ and $\rho^\pm\rho^\mp$ are beginning to provide constraints on α that are better than obtained from the CKM fit. More data will improve the situation. Data on $B^\pm \to DK^\pm$ may soon constrain γ beyond the CKM fit. Improved statistics on $b \to s\bar{s}s$ decays will tell us whether we are beginning to see new physics. Soon, we will begin to get CP Violation results from the Tevatron including results on CPV and mixing in B_s decays.

2.2. Baryonic B Meson Decays in BELLE and BaBar

As statistics have improved, BELLE and BaBar have begun to observe a large variety of B meson decay modes containing baryons. The quark level processes for these decays are shown in Fig. 4. These decays will help test and develop our knowledge of strong interactions. With them we can study patterns of branching fractions, the baryon-antibaryon mass spectrum, factorization, and hadronization. These decays also offer the possibility of new methods of studying CP violation and T violation. They can also be used to search for exotic quark states such as pentaquarks, a hot topic of late that will be discussed below.

The most abundant of these are expected to involve the process $b \to c(W^-)$, a CKM-favored tree-level decay. Examples are

$$\begin{aligned} B^o &\to \Lambda_c^+\bar{p} \\ B^- &\to \Lambda_c^+\bar{p}\pi^- \\ B^o &\to \Lambda_c^+\bar{p}\pi^-\pi^+ \text{ and} \\ B^o &\to D^{o,(*)}\bar{p}p. \end{aligned} \tag{19}$$

Charmless baryonic decays are due to the CKM-suppressed tree level decay $b \to u(W^-)$ as well as the $b \to s(q\bar{q})$ Penguin.

The decay $B^o \to \Lambda_c^+\bar{p}$[21] is the first observation of a B Meson 2-body baryonic decay. The branching fraction is $(2.19^{+0.56}_{-0.49} \pm 0.32 \pm 0.57) \times 10^{-5}$ and is larger than the $\bar{p}p$ decay mode for which only an upper limit currently exists. The branching fractions for $B^o \to D^{o,(*)}\bar{p}p$ are also published[22] and are at the 10^{-4} level.

The BELLE Collaboration showed a preliminary result on the Dalitz plot for the decay $B^- \to \Lambda_c^+\bar{p}\pi^-$, Fig. 5, that shows an enhancement in the $\Lambda_c\bar{p}$ mass spectrum at a mass of 3.33±0.02 GeV/c^2 with a width of 0.15± 0.05 GeV/c^2. This is shown clearly in the projection of the Dalitz plot onto the $\Lambda_c\bar{p}$ axis, Fig. 6. There are cuts to eliminate the low mass regions in $M^2_{\Lambda_c\pi^-}$ and $M^2_{\bar{p}\pi^-}$ to avoid known resonances. A helicity analysis of the $\Lambda_c\bar{p}$ is underway and a preliminary result was shown.

A set of branching fractions for charmful decays shows a strong suppression of lower multiplicity decays with the branching fractions of 2-body, 3-body and 4-body decays roughly in the ratio of 0.1, 1, 10.

Several charmless decays have now been seen.

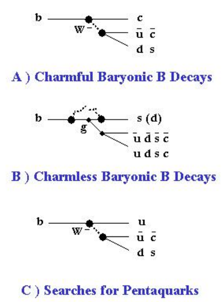

Figure 4. Quark level processes for baryonic decays of B mesons.

The family of $B^{+,o} \to p\bar{p}h^{+,0}$ decays have been studied[23]. In all cases the $p\bar{p}$ mass spectrum from these decays shows strong peaking near threshold. BR($p\bar{p}K^+$) is greater than BR($p\bar{p}\pi^+$), as might be expected by analogy to meson decays. BR($p\bar{p}K^o$), however, is less than BR($p\bar{p}K^+$), unlike for the mesons. A new result, shown in Fig. 7, is the decay $B^+ \to \Lambda\bar{\Lambda}K^+$[24]. This decay is a $b \to s\bar{s}s$ decay, the baryon analog to ϕK_s.

There is still no evidence for the $p\bar{p}$ decay and the BaBar upper limit on the branching fraction is now 2.7×10^{-7}[25].

2.3. Rare Hadronic B Meson Decays

These are decays that are dominated by CKM-suppressed $b \to u$ tree diagrams or decays with $b \to s$ or $b \to d$ Penguin diagrams. They have small branching fractions, typically BR$< 10^{-5}$. It is important to understand these decays because Penguin diagrams are likely to contribute to direct CP violation and $b \to u$ diagrams involve the CKM angle γ. Also, because the SM contributions are small, new physics can compete more favorably so these are excellent places to look for physics beyond the Standard Model.

Results were presented for $B \to \pi\pi, K\pi, KK$, $B \to (\eta,\eta')(K,K^*,\rho,\pi)$, $B \to \rho K, \rho\pi$, $B \to (\eta,\eta',\omega,\phi)(\eta,\eta',\omega,\phi)$, and $B \to \phi K^*, \rho\rho, \rho K^*$.

The decay mode $B^o \to \pi^o\pi^o$[28] has finally been observed and its branching fraction measured to be $(1.9 \pm 0.5) \times 10^{-6}$. This decay is important for the study of α.

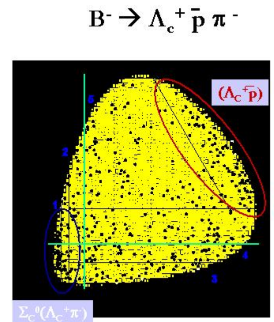

Figure 5. Dalitz plot for $B^- \to \Lambda_c\bar{p}\pi^-$. $M^2_{\Lambda_c\pi^-}$ is plotted on the X axis and $M^2_{\bar{p}\pi^-}$ is plotted on the Y-axis. The Σ_c^o's form the vertical band on the left lower edge of the plot. The $\Delta(1232)$ would be present as a horizontal band at the lower part of the plot. The slanted accumulation along the upper right boundary suggests a structure in $\Lambda_c\bar{p}$.

BELLE observes $B^o \to \rho^o\pi^o$[29] with a significance of 3.5 σ and measures its branching fraction to be $(5.1 \pm 1.6 \pm 0.9) \times 10^{-6}$, somewhat higher than theoretical predictions. Since a study of the $B^o \to \rho\pi$ Dalitz plot offers an excellent method for extracting α, this is also good news!

The $K\pi$ decay modes are now well measured. These decays are governed by a combination of CKM-suppressed tree amplitudes and Penguin amplitudes so their branching fractions shed light on the relative strengths of these amplitudes. In particular, $B^+ \to K^o\pi^+$ receives contributions only from the $b \to s\bar{s}s$ Penguin so provides a good determination of the strength of that diagram. At the time of this meeting, it was claimed that no direct CP violation was observed in $K\pi$ modes. However, the HFAG value of A_{CP} for $B^o \to K^+\pi^-$ was given as -0.095 ± 0.028, or a little over 3 σ. New data that became available

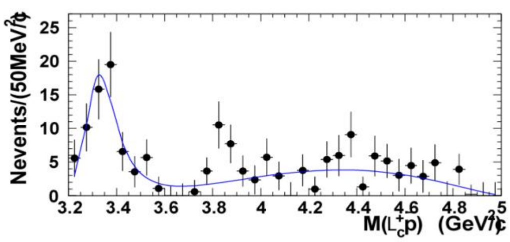

Figure 6. The $\Lambda_c \bar{p}$ mass spectrum from the decay $B^- \to \Lambda_c \bar{p} \pi^-$ with cuts to eliminate particles that are clearly associated with low mass $\Lambda_c \pi$ and $\bar{p}\pi$ resonances

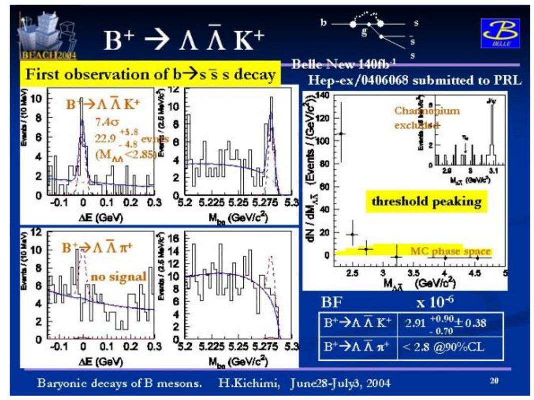

Figure 7. BELLE results on $B^+ \to \Lambda\bar{\Lambda}K^+$. Shown on the left are four plots showing the presence of the signal in $(\Delta E, M_B)$. Shown on the right upper is the peaking in $M_{\Lambda\bar{\Lambda}}$. Note that the insert shows a signal for $J/\psi \to \Lambda\bar{\Lambda}$ that is removed. The lower right gives the branching fraction result.

later in the summer from BaBar[5] gives a value,

$$\frac{n_{K^-\pi^+} - n_{K^+\pi^-}}{n_{K^-\pi^+} + n_{K^+\pi^-}} = -0.133 \pm 0.030 \pm 0.009 \quad (20)$$

which was taken as positive evidence for direct CP violation in this decay. This is the first convincing evidence for Direct CP violation in B decays, at least in my opinion.

The family of decays $B \to KK$ can give information, through their branching fractions, on rescattering. So far, no evidence of rescattering has been observed.

The decays $B \to (\eta, \eta')(K, K^*)$[30] have the pattern that

$$\begin{aligned} BF(B \to \eta' K) &>> BF(B \to \eta K) \\ BF(B \to \eta K^*) &>> BF(B \to \eta' K^*) \end{aligned} \quad (21)$$

This is now understood as a consequence of destructive interference among the several diagrams contributing to these decays and to $\eta - \eta'$ mixing.

The decays $B \to (\eta' K_s, \phi K_s, K^+K^-K_s)$ should show mixing-induced CP asymmetries that are to first order the same as that observed in $B^o \to \psi K_s$ but other diagrams can cause a difference. The quantity

$$\Delta S = S(\eta' K_s \text{ or similar mode}) - S(\psi K_s) \quad (22)$$

measures this difference. The size of various branching fractions constrains the various perturbing amplitudes and limits the amount by which they can contribute to ΔS. Grossman et al. have shown that ΔS is less than a parameter called $\xi_{\eta' K_s}$ that can be derived from the branching fractions for these rare decays[26]. This quantity has now been shown to have a value of $|\xi_{\eta' K_s}| < 0.17$[27]. So far, measurements of CP violation in these modes lack the precision to test this constraint.

We also saw new data on the processes $B \to VV$. Since both CP even and CP odd amplitudes are present, these decays are more complicated but their angular distributions also offer additional observables for detecting CP violation or New Physics. They also provide an additional window onto both strong and weak interaction dynamics.

Polarization measurements were shown for $B \to \rho\rho$, ρK^*, and ϕK^*. Theory predicts that all should be strongly longitudinally polarized.

While this is true for $\rho\rho$ and $K^*\rho$, the degree of longitudinal polarization for ϕK^* is lower than expected ($\sim$0.5). We mentioned above how the high degree of longitudinal polarization of $\rho\rho$ can be used to help extract α.

2.4. Results on Lifetimes, Mixing CP Violation, and Rare B Decays at the Tevatron

CDF and D0 have been assembling the experimental and analytical tools required to contribute to B physics. The strength of the Tevatron for B physics is the high rate of production of hadrons containing b-quarks and the fact that there is enough energy to produce all species of b-hadrons. The liabilities, relative to e^+e^- machines, are that the B's occur in only one out of every 500-1000 events, leading to a challenging trigger problem; and that the underlying event is more complex and lacks some of the powerful constraints available in e^+e^-. Nevertheless, these challenges are being met and proof-of-principle to be able to do quality B physics has been established. Key measurements are expected to be B mixing - Δm_d, Δm_s; $\Delta\Gamma$, especially for B_s, precision lifetimes, CP violation, rare decays, spectroscopy, and dynamics.

CDF has implemented new triggers[31] that improve its sensitivity to B physics:

- A dimuon trigger with a very low $P_t(\mu)$ requirement of only 1.5 GeV/c;
- A lepton plus displaced-track trigger, that requires in addition to a lepton with $P_t(\mu \text{ or } e) > 4.0$ GeV/c, evidence for one track with detachment, d, from the interaction point of $120\mu m < d < 2$mm; and
- A two displaced-track trigger, that is two tracks each with $P_t > 2.0$ GeV/c and each with detachment, d, from the interaction point of $120\mu m < d < 2$mm and $\Sigma P_t > 5.5$ GeV/c.

This has increased their sensitivity for hadronic modes by four orders of magnitude from Tevatron Run I!

With this trigger and their upgraded detector, CDF has obtained the results for B lifetimes shown in Table 2.

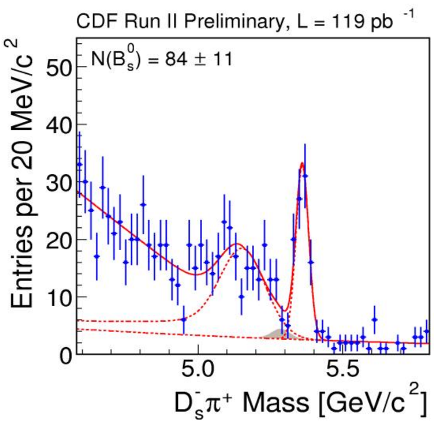

Figure 8. $B_s \to D_s^-\pi^+$ from CDF.

From CDF data, one has $\tau_{B+}/\tau_{B^o} = 1.080 \pm 0.042$(tot.) and $\tau_{B_s}/\tau_{B^o} = 0.890 \pm 0.072$(tot.). In addition, they measure the Λ_B lifetime to be $\tau_{\Lambda_B} = 1.25 \pm 0.26 \pm 0.10$ ps. An important point is that CDF is already able to make excellent lifetime measurements, comparable to the world's best. However, they are still statistics limited, and statistics will improve greatly over the next few years.

CDF also showed measurements of the B^o mixing parameter Δm_d, based on both the decay mode $B^o \to \psi K^*(K^* \to (K\pi))$ and $B^o \to D^-\pi^+(D^- \to K^+\pi^-\pi^-)$. Their result is $(\Delta m_d = 0.55 \pm 0.10 \pm 0.01)$ ps^{-1}, in good agreement with the world average.

For B_s mixing, they have a clean B_s signal in the decay mode $B_s \to D_s^-\pi^+$, with $D_s^- \to \phi\pi^-$, shown in Fig. 8. The current projection is that by the end of 2005 they will have an integrated luminosity of more than 500 pb^{-1} and their sensitivity for Δm_s will reach the current limit. Between then and 2008, they hope to reach 18 ps^{-1} with 1.8 fb^{-1} and 24 ps^{-1} with 3.2 fb^{-1} (the so-called "base" and "design" goals for the Tevatron integrated luminosity).

CDF showed their work on the charmless B

Table 2
B Lifetimes from CDF RUN II

State	CDF(this conf) ps	PDG '03 ps	Single best ps
B^+	$1.662 \pm 0.033 \pm 0.008$	1.671 ± 0.018	$1.695 \pm 0.026 \pm 0.015$
B^o	$1.539 \pm 0.051 \pm 0.008$	1.537 ± 0.015	$1.529 \pm 0.012 \pm 0.029$
B_s	$1.461^{+0.008}_{-0.010}$	1.461 ± 0.057	$1.36 \pm 0.09^{+0.06}_{-0.05}$

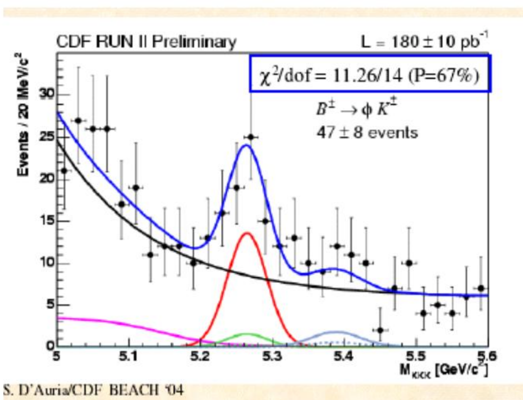

Figure 9. $B^+ \to \phi K^+$ signal used to search for Direct CP violation by CDF.

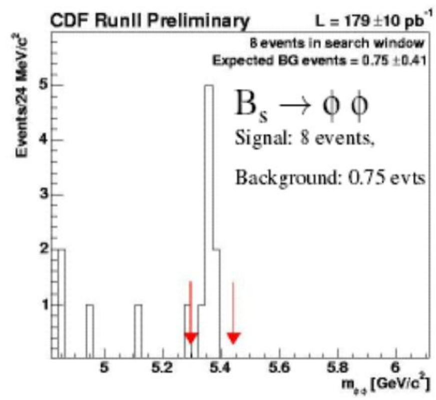

Figure 10. $B_s \to \phi\phi$ signal from CDF

decays:

$$\begin{aligned} B_u &\to \phi K^{\pm} \\ B_s &\to \phi\phi \\ B_{d,s} &\to h^{\pm}h^{\mp} \text{ where h } = K, \pi \end{aligned} \tag{23}$$

These are decay modes that are good candidates for Direct CP violation.

The decay $B^{\pm} \to \phi K^{\pm}$ is expected to be almost pure $b \to s\bar{s}s$ Penguin (there is a CKM-suppressed annihilation diagram that is expected to be very small). Figure 9 shows CDF's signal. The result of their search for Direct CP violation is

$$\begin{aligned} A_{CP} &\equiv \frac{\Gamma_{B^+\to\phi K^+} - \Gamma_{B^-\to\phi K^-}}{\Gamma_{B^+\to\phi K^+} + \Gamma_{B^-\to\phi K^-}} \\ &= 0.07 \pm 0.17^{+0.06}_{-0.05} \end{aligned} \tag{24}$$

CDF has also observed the decay $B_s \to \phi\phi$. The signal is shown in Fig. 10. This is a Penguin decay that has not been observed before. Since it is a vector-vector decay, it can have CP even and odd amplitudes. It may be useful in studying $\Delta\Gamma$ and it may be a good place to look for new physics since very little Direct CP violation is expected in this mode in the Standard Model.

CDF also showed the status of its analysis of $B_{d,s} \to h^{\pm}h^{\mp}$ where $h = K, \pi$. This requires them to unfold the two body spectrum, shown in Fig. 11, based on invariant mass measurements and particle identification (mostly dE/dx). Their current result for Direct CP violation is

$$A_{CP}(B^o \to K\pi) = 0.02 \pm 0.15 \pm 0.017 \tag{25}$$

With their vertex trigger, CDF has also been able to collect high statistics samples of charm decays. They have measured the Cabibbo suppressed decays $D^o \to \pi^+\pi^-, K^+K^-$ and looked for Direct CP violation. Their results are

$$\begin{aligned} A_{CP}(D^o) \to K^+K^- &= 2.0 \pm 1.2 \pm 0.06\% \\ A_{CP}(D^o) \to \pi^+\pi^- &= 1.0 \pm 1.3 \pm 0.06\% \end{aligned} \tag{26}$$

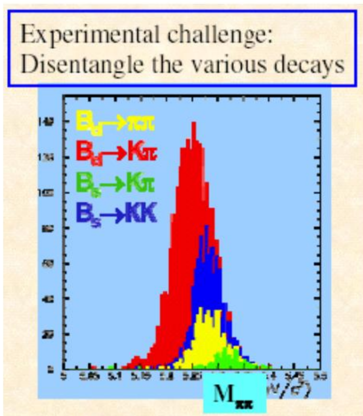

Figure 11. $B_{d,s} \to h^+h^-$, where h=π or K in CDF.

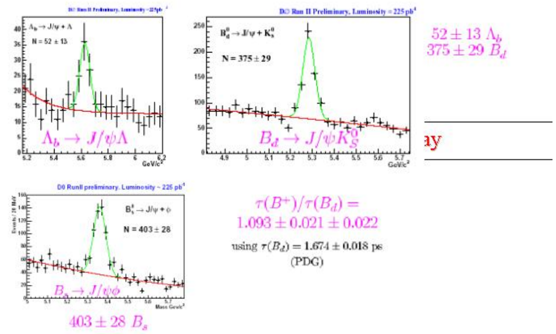

Figure 12. D0 B signals. Upper left is the mass spectrum for $J/\psi\Lambda$ showing a Λ_b; upper right is the signal for $B^o \to J/\psi K_s$; and the lower left shows $B_s \to J/\psi\phi$.

The upgraded D0 detector similarly has shown the ability to reconstruct states with bottom and charm, to measure lifetimes and mixing, and to search for rare decays. Figure 12 shows results on the observation of B_d, B_s and Λ_B in D0. D0 has a result for the lifetime ratio $\tau_{B+}/\tau_{B^o} = 1.093 \pm 0.021 \pm 0.022$.

CDF and D0 are both carrying out searches for the decay $B_s \to \mu^+\mu^-$. This decay can be enhanced rather substantially from its rather small SM value by SUSY effects and is a good place to look for new physics. CDF also studied $B_d \to \mu^+\mu^-$. CDF results are:

$$\begin{aligned} BR(B_s \to \mu^+\mu^-) &< 7.5 \times 10^{-7}\ 95\%\ \text{CL} \quad (27) \\ BR(B_d \to \mu^+\mu^-) &< 1.9 \times 10^{-7}\ 95\%\ \text{CL} \end{aligned}$$

These results already provide constraints on SuperSymmetry.

D0 is doing a blind analysis of this decay. While they have not yet opened the box, D0 have accumulated about 180 pb^{-1} for this study. The expected upper limit is about 10^{-6} at 95% CL.

2.5. HQET Parameters and the Extraction of V_{cb}

HQET is used to extract V_{cb} from B semileptonic decays. A common set of HQET parameters[32] appear in expressions for

- lepton energy moments in $B \to X_c l\nu$;
- hadronic mass-squared moments in $B \to X_c l\nu$;
- q^2 moments in $B \to X_c l\nu$;
- photon energy moments in $B \to X_s\gamma$; and
- the semileptonic width.

CLEO presented a combined fit to all these processes and $|V_{cb}|$ to get a new preliminary result

$$|V_{cb}| = (42.4 \pm 0.8) \times 10^{-3}. \quad (28)$$

They expect to reduce the experimental errors even more when all the data are included.

DELPHI showed new fits to Operator Product Expansion parameters and used them to get

$$\begin{aligned} &|V_{cb}| \quad (29) \\ &= 0.0421 \times (1 \pm 0.014_{meas} \pm 0.014_{fit} \pm 0.015_{th}) \end{aligned}$$

CDF showed the first measurements of hadronic moments in a semileptonic B decay, $B \to D^{**o} l\nu$, performed at a hadron collider.

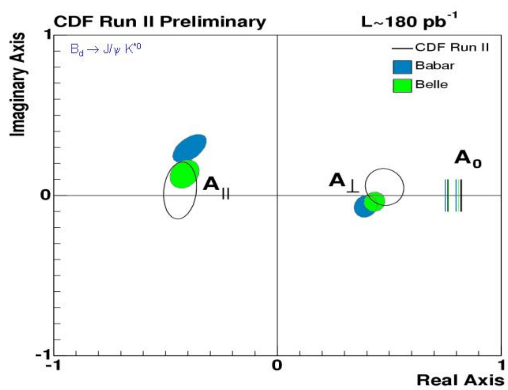

Figure 13. The amplitudes A_o, $A_\perp$, and $A_{||}$ for $B_d \to J/\psi K^{*o}$ from CDF with a comparison to results from BELLE and BaBar.

2.6. Polarization Measurements at the Tevatron

The Tevatron experiments have shown results on polarization measurements for $B \to VV$ decays. Fig. 13 shows the three transversity amplitudes for $B_d \to J/\psi K^{*o}$ obtained from analysis of 180 pb^{-1} of data and their comparison to results from BELLE and BaBar[33]. CDF also showed the amplitudes for the decay $B_s \to J/\psi\phi$! This shows that a variety of CP studies will be accessible to CDF and D0.

2.7. Hadron Production of Particles Containing b-quarks

HERA-B presented results from data they took in 2002-2003. They observed both hidden and open beauty production produced by 920 GeV/c protons. They have a preliminary result for Υ production of 3.4±0.8 pb/nucleon, which is in good agreement with the result from E605 at Fermilab. They have done a global fit that is consistent with no nuclear suppression. For open beauty production they have a preliminary result based on 35% of their data:

$$\sigma(b\bar{b}) = 12.3^{+3.5}_{-3.2} \text{ nb/nucleon} \quad (30)$$

3. B PHYSICS, THE NEXT GENERATION HADRON COLLLIDER EXPERIMENTS

The next generation of B physics experiments will take place at hadron colliders. This will include dedicated B physics experiments – LHCb at the LHC and BTeV at the Tevatron. These will study B hadrons produced in the forward direction. Just as today's general purpose, high P_t central region detectors, CDF and D0, can study some topics in B physics quite well, similarly the two large general purpose high P_t detectors at the LHC, ATLAS and CMS, can also do some B physics, especially rare decays containing leptons, which are easy for them to trigger on.

3.1. Rare B Decays at the LHC

The results for a selected set of rare decays are shown in Table 3. LHCb [34] can detect a large variety of hadronic final states in addition to the ones shown here[35].

3.2. BTeV

BTeV[36] is a dedicated B physics experiment at the Tevatron Collider. Its main features are a silicon pixel vertex detector with 23 million pixels of 50 × 400 μm, embedded in a dipole field centered on the Interaction Region; a trigger that selects events at the lowest level based on evidence for a detached vertex and based on massively parallel computing; a forward tracker based on microstrip detectors and straw chambers; a Ring Imaging Cherenkov counter for charged particle identification; a $PbWO_4$ crystal calorimeter for γ, π^o, and η reconstruction; and a muon detector with proportional tubes embedded in a toroid.

With this detector, BTeV will study B mixing and CP violation to make high precision measurements of CKM parameters to look for new physics. It will also study many rare B decays as well as B and charm spectroscopy and dynamics. The sensitivity of BTeV to various B decays that are used to determine the parameters of the CKM matrix are given in Table 4.

Table 3
Rare Decays at the LHC

Decay	ATLAS		CMS		LHCb	
	signal/backgnd	luminosity	signal/backgnd	luminosity	signal/backgnd	luminosity
$B \to \phi\gamma$	2500/-	20 fb^{-1}	-		9300/-	2 fb^{-1}
$B \to K^{*o}\gamma$	4200/-	20 fb^{-1}	-		35000/-	2 fb^{-1}
$B \to K^{*o}\mu\mu$	1400/-	20 fb^{-1}			4400/-	2 fb^{-1}
$B_s \to \mu^+\mu^-$	92/ 660	100 fb^{-1}	26/<6	100 fb^{-1}	17/<120	2 fb^{-1}
$B_d \to \mu^+\mu^-$	14/660	100 fb^{-1}	4/<6	100 fb^{-1}		

Table 4
Summary of physics reach for key CKM parameters with 2 fb^{-1} in BTeV

Reaction	$Br(B) \times 10^{-6}$	# of events	S/B	Parameter	Error or (value)
$B \to \pi^+\pi^-$	4.5	14,600	3	asymmetry	0.03
$B_s \to D_s^+ K^-$	300	7,500	7	$\gamma - 2\chi$	8^o
$B^o \to J/\psi K_s, J/\psi \to l^+l^-$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s^+\pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o(K^+\pi^-)K^-$	0.17	170	1		
$B^- \to D^o(K^+K^-)K^-$	1.1	1000	>10	γ	13^o
$B^- \to K_s\pi^-$	12.1	4600	1		$<4^o$ +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	theory error
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	4^o
$B_s \to J/\psi\eta$	330	2,800	15		
$B_s \to J/\psi\eta'$	670	9,800	30	$\sin 2\chi$	0.024

4. KAON PHYSICS RESULTS

4.1. A New Measurement of $|V_{us}|$ from KTeV

KTeV reported on its new measurement of $|V_{us}|$[37]. This is a remarkable story that provides an interesting lesson for all of us. V_{us}, or $\sin\theta_c$, more often referred to as the sine of the Cabibbo angle, was introduced by Nicola Cabibbo[38] to describe the strength of the strangeness violating part of weak hadronic decays. It has emerged as a key parameter of the Standard Model, basically determining the pattern of intergenerational mixing. It appears in many theoretical expressions to very high powers. The precise experimental determination of this quantity is crucial and goes back to the early 1960's. It is therefore very surprising that new measurements should move this quantity outside its error bars!

The determination of V_{us} is based on measuring the partial width for semileptonic K decay, which is given by

$$\Gamma_{Kl3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW} \times (1 + \delta_K^l) C^2 |V_{us}|^2 f_+^2(0) I_K^l \quad (31)$$

Here l refers to the lepton (either e or μ), G_F is the Fermi constant for weak decays, M_K is the kaon mass, S_{EW} is a short-distance radiative correction, $f_+(0)$ is the value of the form factor at zero momentum transfer , I_K^l is a phase space integral, which depends on the semileptonic formfactors, and C^2 is 1(1/2) for neutral(charged) kaon decays. The PDG[39] uses only $K \to \pi e\nu$ to determine V_{us} because they judge that there are large uncertainties in the phase space integral for semimuonic decays.

There have actually been two indications of problems somewhere in the determination of V_{us}. First, the PDG's value is derived only from $K \to$

$\pi e\nu$ decays. Other decays, such as hyperon decays, are viewed as having complications that make them less reliable. However, as shown in Cabibbo's talk, the hyperon decays give a consistent but different result of 0.2250 ± 0.0027. Second, there has for some time been a statistically marginal discrepancy at the 2-3 σ level in the unitarity relation

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 \qquad (32)$$

This has sparked a lively reevaluation of the determination of $|V_{ud}|$, which is the dominant term. However, a recent determination of V_{us} from charged kaon decays, Brookhaven experiment 865[40], provided a first indication of a problem with the accepted value of $|V_{us}|$ and suggested that it might be at the root of the discrepancy.

KTeV's approach is to measure five partial width ratios using 6 decay modes of the K_L that account for more than 99.9% of the total decay rate. It has between 10^5 and 10^6 events in each mode. The five partial width ratios are converted to branching fractions for the 6 decay modes and then these are converted to partial widths using the well-measured K_L lifetime for the total width.

One new feature of the KTeV analysis is to include higher order terms in t, the momentum transfer to the $l\nu$ system, in the form factors[41]:

$$f_+(t) = f_+(0)(1 + \lambda'_+ \frac{t}{M_\pi^2} + \frac{1}{2}\lambda''_+ \frac{t^2}{M_\pi^4}) \qquad (33)$$

$$f_o(t) = f_+(0)(1 + \lambda_o \frac{t}{M_\pi^2}) \qquad (34)$$

Since f_o is multiplied by the lepton mass, it is only significant in the semimuonic decay. The t dependence of the form factors affects the phase space integral. KTeV discovered that the inclusion of the λ''_+ term changed the phase-space integral enough to affect the result. KTeV also used a more modern and complete calculation of the radiative corrections[42].

The partial widths obtained by KTeV are compared to those of the PDG in Fig. 14. Four of the six KTeV mesurements are inconsistent with the PDG values[39].

KTeV also demonstrated the consistency of the semi-electronic and semi-muonic decays by showing that lepton universality was respected:

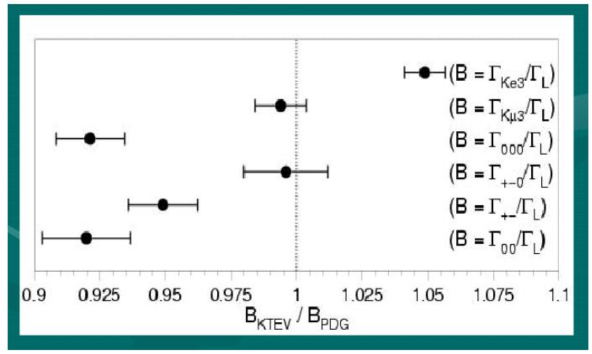

Figure 14. A comparison of the six partial widths measured by KTeV with the PDG world averages.

$$\left(\frac{G_F^\mu}{G_F^e}\right)^2 = 0.9960 \pm 0.0048 \qquad (35)$$

For their final value for $|V_{us}|$, they averaged the semi-electronic and semi-muonic results.

The final result is

$$|V_{us}| = 0.2252 \pm 0.0008_{KTeV} \pm 0.0021_{ext} \qquad (36)$$

Here the "external" uncertainty comes from the theory calculation of $f_+(0)$, the value of the K_L lifetime, and the radiative corrections.

While incompatible with the PDG value of $V_{us} = 0.2196 \pm 0.0023$, it is compatible with the E865[40] result. When the new KTeV value is used, the first row unitarity relation is satisifed to about the 1 σ level. The new result is in good agreement with the hyperon determinations.

There are many lessons that can be learned from this. First, as experiments improve, it may well be worthwhile and rewarding to chase down the inconsistencies and small mysteries left over from earlier eras. It is not good science to sweep problems under the rug, especially in the case of such a fundamental parameter. Second, results can change because experimental techniques improve, resulting in higher statistical precision and better control over systematics. But equally, theory can improve and produce better calculations and corrections. The data need to be constantly revisited to see if they can benefit from the use of these improved inputs. Third, the PDG, which does an incredibly valuable and remarkable job, is not perfect and is limited in the its ability to handle outlyers in the datasets that it averages. It is useful to remember this and to review and critically judge the inputs to averages when there are signs of problems. Finally, it is worth noting that the KTeV result is a by-product of an experiment that had much higher priority goals. Nevertheless, an important result about a fundamental constant of nature has been obtained by the determination of individuals to truly "mine" the data.

4.2. First Results on Direct CP Violation with Charged Kaons at NA48

In 2003, NA48 took data with a charged kaon beam. The exposure amounted to about 50 "effective days" of data-taking. Data from the last 28 days, a period of stability, were presented.

They studied the two decays

$$\begin{aligned} K^+ &\rightarrow \pi^+\pi^-\pi^+ \text{ Charged or C decay} \\ K^+ &\rightarrow \pi^+\pi^o\pi^o \text{ Neutral or N decay.} \end{aligned} \quad (37)$$

These decays receive contributions from two amplitudes: a dominant $\Delta I = 1/2$ amplitude and a much smaller $\Delta I = 3/2$ amplitude that is considered a contamination. There are two $\Delta I = 1/2$ amplitudes that can interfere and can have different weak and strong phases. This can lead to Direct CP violation. The decay rate may be written as

$$|A(K \rightarrow 3\pi)|^2 \propto 1 + g \times u \quad (38)$$

where $u = (s_3 - s_o)/M_\pi$ and $s_i = (p_K - p_i)^2$ and $s_o = \Sigma s_i$. Direct CP violation is revealed as a difference in the linear slopes "g" between K^+ and K^-, respectively:

$$A_g^{C,N} \equiv \frac{g_+ - g_-}{g_+ + g_-} \quad (39)$$

The first, already completed, run should reach a sensitivity of about $2.5 - 5.0 \times 10^{-4}$. It will require a few billion charged kaon decays to reach 10^{-4}. The experiment is running again in 2004 for 60 days.

4.3. Status Report on BNL E949, $K^+ \rightarrow \pi^+\nu\bar{\nu}$

The decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$ gives a determination of $|V_{td}|$ that is nearly free of theory uncertainties down to about the 7% level. BNL E949 observed one such decay and presented it in 2000. They have seen one additional candidate in their 2002 run. They have now implemented a full likelihood analysis that admits ambiguous events and gives them proper weights. The result of this reanalysis is

$$B(K^+ \rightarrow \pi^+\nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10} \quad (40)$$

corresponding to a value

$$0.005 < |V_{td}| < 0.027. \quad (41)$$

These results are consistent within their large uncertainties with the Standard Model.

4.4. $K^o \rightarrow \pi^o l^+ l^-$ from KTeV and NA48

This decay can receive contributions from diagrams shown in Fig. 15. The first two have the potential to produce CP violation. The third is CP conserving. According to the Standard Model, the CP violating amplitudes should dominate the CP conserving ones in $K^o \rightarrow \pi^o e^+ e^-$ and should be comparable to the CP conserving ones in $K^o \rightarrow \pi^o \mu^+\mu^-$.

From the 1997 dataset, KTeV sets a limit of

$$BR(K_L^o \rightarrow \pi^o\nu\bar{\nu}) < 5.9 \times 10^{-7} \text{ 90\% CL[43]} \quad (42)$$

and from the full 1997 and 1999 datasets, KTeV sets a limit of

$$BR(K_L \rightarrow \pi^o e^+ e^-) < 2.8\times10^{-10} \text{ 90\% CL[44].} \quad (43)$$

From the 1997 and 1999 dataset, KTeV sets a limit on

$$BR(K_L \rightarrow \pi^o \mu^+ \mu^-) < 3.8\times10^{-10} \text{ 90\% CL[45].} \quad (44)$$

NA48 reported first observations of two decays of the K_s and measurements of their branching fractions:

$$BR(K_S \rightarrow \pi^o e^+ e^-) \quad (45)$$

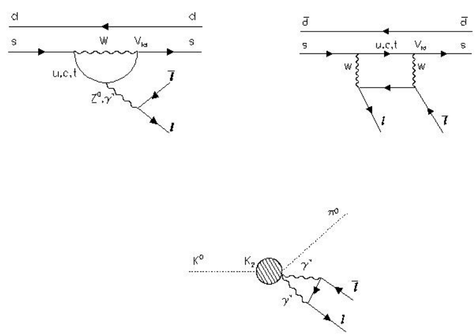

Figure 15. Three diagrams contributing to the decay $K^o \to \pi^o l^+ l^-$.

$$= (5.8^{+2.8}_{-2.5} \pm 0.3 \pm 0.8 \text{ theory}) \times 10^{-9}[46]$$
$$BR(K_S \to \pi^o \mu^+ \mu^-)$$
$$= (2.9^{+1.5}_{-1.2} \pm 0.2) \times 10^{-9}[47].$$

5. FUTURE KAON EXPERIMENTS

5.1. KOPIO

KOPIO[48] is an experiment to measure the decay $K_L \to \pi^o \nu \bar{\nu}$ that will run at Brookhaven National Laboratory. The branching fraction of this decay measures $IM(V_{ts}^* V_{td})$ and is expected to be about 0.26×10^{-10}. This is a "golden" decay mode but it is very rare and the decay is very hard to detect against substantial backgrounds so that this measurement will be a major experimental challenge.

5.2. CKM

CKM[49] is an experiment to measure $K^+ \to \pi^+ \nu \bar{\nu}$, a rare decay that provides a measure of $|V_{td}|$. The theory error is about 7% and is due to uncertainties in the charm contribution. The goal is to reach a statistical uncertainty that is smaller than the theory error, which requires about 200 events. The decay is sensitive to new physics in $s \to d$ transitions and is orthogonal to the $\sin 2\beta$ measurement in the B system. The first version of CKM used a separated kaon beam. Because of funding problems, a less expensive version, based on an unseparated beam and an existing beamline and experimental enclosure, is being planned. The beam will operate at higher energies. Because of the high rate of pions in the beam, special detectors are required to handle the high rate. These are being developed.

6. HYPERON PHYSICS

6.1. Status of HyperCP, A Search for CP Violation in Hyperon Decays

HyperCP searches for CP violation in Ξ and Λ decays. Since parity is violated in the decays,

$$\Xi \to \Lambda \pi^-, \Lambda \to p \pi^- \tag{46}$$

their angular distributions are described by

$$\frac{dN}{d\cos\theta}(\Lambda, p) \propto (1 \ + \ \alpha_{\Xi,\Lambda} \vec{P}_{\Xi,\Lambda}, \cos\theta) \tag{47}$$

The decay constant α is related to the S and P-wave angular momentum amplitudes by

$$\alpha \ = \ \frac{2RE(S^* P)}{|S|^2 \ + \ |P|^2} \tag{48}$$

Both α_Ξ and α_Λ are large. If CP is conserved then $\alpha_\Lambda \ = \ -\alpha_{\bar{\Lambda}}$ and $\alpha_\Xi \ = \ -\alpha_{\bar{\Xi}}$. Then, a CP violating asymmetry is defined as

$$A_\Lambda = \frac{\alpha_\Lambda + \alpha_{\bar{\Lambda}}}{\alpha_\Lambda - \alpha_{\bar{\Lambda}}} \text{ and } A_\Xi = \frac{\alpha_\Xi + \alpha_{\bar{\Xi}}}{\alpha_\Xi - \alpha_{\bar{\Xi}}}. \tag{49}$$

These parameters are related to the S and P wave strong phase differences and the S and P wave weak phase diffrences, both of which must be non-zero for there to be an effect. HyperCP has shown that the $\Lambda - \pi$ strong phase shift difference is $4.6 \pm 1.4 \pm 1.2^o$.

HyperCP uses unpolarized Ξ^- so that the Λ's have a polarization given by the decay constant α_Ξ and the angular distribution of the Λ is

$$\frac{dN}{d\cos\theta}(\Lambda p) \propto (1 \ + \ \alpha_\Lambda \alpha_\Xi \cos\theta). \tag{50}$$

The asymmetry is

$$A_{\Xi\Lambda} \ = \ \frac{\alpha_\Xi \alpha_\Lambda - \alpha_{\bar{\Xi}} \alpha_{\bar{\Lambda}}}{\alpha_\Xi \alpha_\Lambda + \alpha_{\bar{\Xi}} \alpha_{\bar{\Lambda}}}. \tag{51}$$

Given that the CP violation will be small

$$A_{\Xi\Lambda} \sim A_{\Xi} + A_{\Lambda}. \quad (52)$$

The Standard Model prediction for this asymmetry is a few $\times 10^{-5}$. New physics, such as SUSY, can increase this significantly. HyperCP will measure $A_{\Xi\Lambda}$ with a sensitivity of around 2×10^{-4} and so is basically looking for new physics effects. This is two orders of magnitude better than the existing limit.

HyperCP presented a preliminary result based on an analysis of about 10% of the data. The result is

$$A_{\Xi\Lambda} = (0.0 \pm 5.1 \pm 4.2) \times 10^{-4}. \quad (53)$$

6.2. Hyperon Physics in KTeV

KTeV reported a result on

$$\Xi^o \rightarrow \Sigma^+ \mu^- \bar{\nu} \quad (54)$$

based on 300 million Ξ^o decays recorded in 1999. They have a signal of 9 events with no background. Their preliminary result for the branching fraction is $(4.3 \pm 1.4) \times 10^{-6}$.

6.3. Hyperon Physics in NA48

NA48 reported a result on the decay $\Xi \rightarrow \Lambda\gamma$ based on 730 events over a background of about 60 events. The decay parameter is

$$\alpha_{\Xi\rightarrow\Lambda\gamma} = -0.78 \pm 0.18 \pm 0.06. \quad (55)$$

The branching fraction is

$$BR(\Xi \rightarrow \Lambda\gamma) = (1.16 \pm 0.05 \pm 0.06) \times 10^{-3}. \quad (56)$$

7. Neutrino Induced Strange Particle Production at MINERVνA

This is a proposal for a new experiment using the NUMI beam to study low energy neutrino interactions with a fine-grained fully active calorimeter[50]. The calorimeter, shown in Fig. 16, will be placed just in front of the MINOS Near Detector so it can use it as a muon ranger. The fiducial volume will be 3 tons CH, 1 ton Fe and 1 ton Pb. Topics that will be studied include quasi-elastic scattering, resonance production, coherent π production, nuclear effects, oscillation physics, σ_T and structure functions, parton distributions, and, of particular interest to this conference, strange and charmed particle production. Topics involving the strange and charm quark include exclusive channel $\sigma(E_\nu)$ measurements that are of interest in cosmology, search for Flavor Changing Neutral Current processes, measurement of CKM matrix elements, and exclusive charm production near threshold that will give a measurement of m_c. The list of interactions containing strange particles that will be studied was given by Solomey[51].

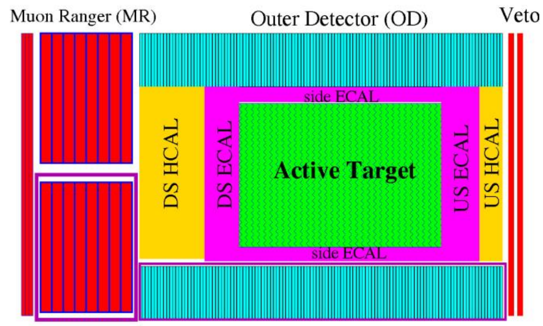

Figure 16. Schematic of the MINERνA Active Target/Calorimeter. The side and downstream parts of the calorimeter have magnetic field.

8. ELECTROWEAK PHYSICS

8.1. Gauge Boson Couplings at LEP

Triple and quartic gauge couplings are a fundamental property of the Standard Model and express its non-Abelian nature. New physics could manifest itself as "anomalous couplings," that is couplings not conforming to the behavior predicted by the SM.

Charged triple gauge couplings (TGCs) predicted by the SM were observed at LEP and measured at the level of 2-4%. So far, no deviation has been observed from the SM and limits have been set on anomalous charged and neutral triple gauge and quartic gauge couplings. The collaborations are still working on the analysis and have produced several new results in 2004. The LEP Electroweak Working Group[52] has combined the results from the four experiments wherever possible to provide a comprehensive picture of what has been learned at LEP.

Future colliders will make even more stringent tests. According to the ATLAS TDR[54], the precisions achievable with only 30 fb^{-1} at the LHC for g_1^Z, κ_γ, and λ_γ are 4×10^{-3}, 2×10^{-2}, and 1×10^{-3}, respectively. From the TESLA TDR[55], at an e^+e^- Linear Collider operating at $\sqrt{s} = 500\,GeV$, with an integrated luminosity of 500 fb^{-1}, these three quantities can each be measured to $3 - 4 \times 10^{-4}$.

8.2. W Mass and Width Measurements at LEP II

W's are produced in pairs at LEP II. With 700 pb^{-1} for each experiment, about 40,000 WW events have been observed. The branching fraction to $WW \rightarrow q\bar{q}l\nu$ is ~44% and to $WW \rightarrow q\bar{q}q\bar{q}$ is ~46%.

Many complex issues must be addressed in order to extract precision values of the mass and width from these events. The current status of the measurements of the mass and width were presented by A. Gupta[56]. Work is still going on and the final LEP results are expected at the end of 2004. A reduction of the uncertainty on the mass from 43 MeV/c^2 to 37 MeV/c^2 is possible.

8.3. Standard Model Higgs in Tevatron Run II

The "golden" channel for observing the Higgs Boson in Run II of the Tevatron is $WH \rightarrow l\nu b\bar{b}$. This process has the largest Higgs branching fraction for $M_H < 135\,\mathrm{GeV/c^2}$ and has the second highest cross section. The QCD background appears tractable. For $M_H > 135\,\mathrm{GeV}^2$, the favored process is direct Higgs production followed by the decay $H \rightarrow WW \rightarrow l\nu l\nu$. The spin of the Higgs provides discrimination against backgrounds, which are now well understood from the background analysis for the WW cross section measurement.

Fig. 17 shows the current limits relative to the SM predictions. It will take significantly more integrated luminosity to reach the SM levels.

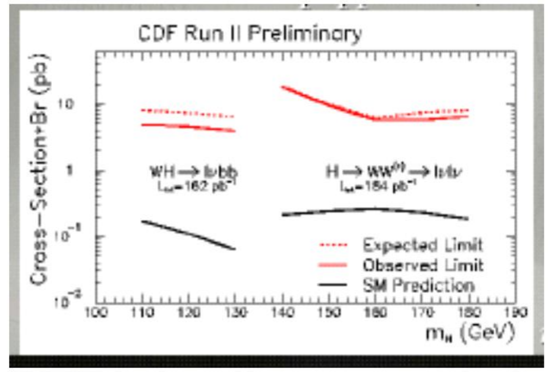

Figure 17. Preliminary results on CDF Higgs search.

The Higgs is constrained by the measurements of the top and W masses. The three masses are related by $\delta M_W \propto (M_{top}^2, \log(M_H))$.

8.4. Top Quark Physics in CDF

There are three recent CDF measurements of the top mass in the leptons+jets channel. These are based on 162 pb^{-1} of data taken in Tevatron Run II. The most accurate method uses the "Dynamical Likelihood Method[57]" and, with 160 pb^{-1} gives

$$M_{top} = 177.8^{+4.5}_{-5.2} \pm 6.2\ \mathrm{GeV/c^2} \qquad (57)$$

The top mass is already measured to an accuracy of a few per cent.The stated goal for Run II is to achieve a total uncertainty of 3 GeV/c^2.

There is a preliminary result for the top pair production cross section. The combined value is $\sigma(t\bar{t}) = 6.7^{+0.7}_{-0.9}$ pb and is consistent with the SM prediction for a top mass of 175 GeV/c^2.

Single top production[58] proceeds by the diagrams shown in Fig. 18. Its measurement provides a direct determination of $|V_{tb}|$. It is also sensitive to new physics. The current 95% confidence level upper limit is 13.7 pb. About 4 times more luminosity is required to make a good determination of $|V_{tb}|$.

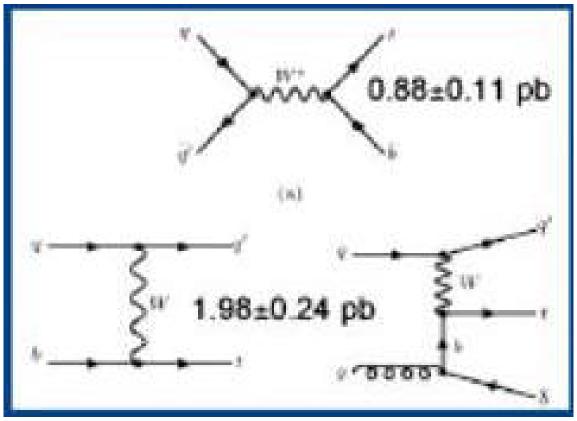

Figure 18. Mechanism for single Top production.

Studies of cross sections, branching fractions, and polarization indicate that at this level of statistics the top quark behaves like a Standard Model top.

8.5. Top Physics at the LHC

The top quark cross section at the LHC, $\sqrt{s}$ = 14 TeV is calculated in Next-to-Leading Order to be about 830 pb or about 100 times the cross section at the Tevatron. The dominant production mechanism at the LHC is gluon fusion as compared to the Tevatron where it is $q\bar{q}$ fusion. Key lines of investigation are determination of the mass to 1 GeV/c^2, search for events with flavor changing neutral currents in decays such as Zq, γq, and gq, search for $t\bar{t}$ resonances, $t\bar{t}$ Yukawa coupling ($t\bar{t}$-Higgs), spin correlations, branching fractions, and single top production for a measure of $|V_{tb}|$.

9. CHARM PHYSICS

9.1. Open and Hidden Charm Results from HERA-B

Data on direct charm production at fixed target energies is actually rather sparse. HERA-B has reported new results for charm cross sections at 920 GeV. They also presented an upper limit for the rare decay $D^o \to \mu^+\mu^- < 2.0 \times 10^{-6}$ at 90% CL.

By comparing J/ψ production on tungsten and carbon wires, HERA-B extracts the A-dependence parameter α as a function of x_F down to $x_F = -0.3$, extending the results of E866 at Fermilab that stopped at about $x_F = -0.1$.

9.2. Heavy Flavor Production and Properties at HERA

H1 presented new data on production of b and c quarks. The production process can be viewed as a convolution of:

$$\text{PhotonStructure} \otimes \text{ Matrix element} \otimes \text{ Proton Structure} \tag{58}$$

Data for the quark fraction F_2 are are in good agreement to NLO QCD calculations.

9.3. FOCUS Results on Semileptonic Form Factors

The FOCUS collaboration reported results on branching fractions and form factors of semileptonic charm decays into vector mesons:

$$\begin{aligned} D^+ &\to \bar{K}^*\mu^+\nu \\ D_s^+ &\to \phi\mu^+\nu \end{aligned} \tag{59}$$

The decay rate for the first of these depends on three helicity amplitudes:

$$\begin{aligned} H_\pm(q^2) &= (M_D + m_{K\pi})A_1(q^2) \mp 2\frac{M_D K}{M_D + m_{k\pi}}V(q^2) \\ H_o(q^2) &= \frac{1}{2m_{K\pi}\sqrt{q^2}} [(M_D^2 - m_{K\pi}^2 - q^2)(M_D + m_{K\pi})A_1(q^2) - 4\frac{M_D^2K^2}{M_D + m_{K\pi}}A_2(q^2)] \end{aligned} \tag{60}$$

The axial and vector form factors are parameterised in a dipole form as

$$\begin{aligned} A_i(q^2) &= \frac{A_i(0)}{1 - q^2/M_A^2} \ (M_A = 2.5\text{GeV/c}^2) \\ V(q^2) \end{aligned} \tag{61}$$

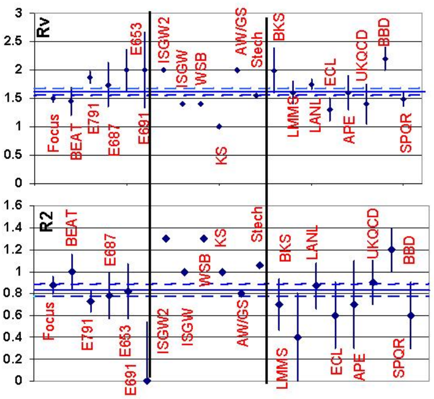

Figure 19. FOCUS Form Factor ratios and results from other experiments (left section); quark model predictions (center section); and the results of LQCD calculations (right section).

$$= \frac{V(0)}{1 - q^2/M_V^2} \; (M_V = 2.1\mathrm{GeV/c^2})$$

For the D^+'s, the pole masses are the values of D_s vector and axial vector mesons as seen in the t-channel.

It has become conventional to factor out A_1 and to present $R_V = \frac{V(0)}{A_1(0)}$ and $R_2 = \frac{A_2(0)}{A_1(0)}$. Additional fit parameters are A and δ, the magnitude and phase of an S-wave-like contribution to the K^* mass peak that FOCUS has shown is necessary to describe this decay[59]. A fit to the data gives the FOCUS results shown in Fig. 19[60]. The figure also shows the data from other experiments and calculations from theoretical models as well as Lattice QCD.

The results for the similar decay $D_s^+ \to \phi\mu^+\nu$ are[61]

$$\begin{aligned} R_V &= 1.549 \pm 0.250 \pm 0.0148 \\ R_2 &= 0.713 \pm 0.202 \pm 0.284 \end{aligned} \tag{62}$$

The form factors are expected to be within 10% of the D^+ form factors. From older results, the R_V values were consistent but the R_2 for $D_s \to \phi l\nu$ was about twice as high as for $D^+ \to K^*\mu\nu$. The new FOCUS results show the expected consistency between the D^+ and Ds decays.

A careful examination of the "wrong sign contribution" to $D^+ \to K\pi\mu\nu$ semileptonic decay candidates provided an indication of an excess that, if attributed to Cabibbo-suppressed $D_s^+ \to K^{*o}\mu\nu$ gives

$$\frac{\Gamma(D_s^+ \to K^*\mu\nu)}{\Gamma(D_s^+ \to \phi\mu\nu)} = (12.9 \pm 3.3 \pm ?)\% \tag{63}$$

The branching fractions[62] for these seimleptonic decays relative to well-known hadronic decays are:

$$\begin{aligned} &\frac{\Gamma(D_s^+ \to \phi\mu^+\nu)}{\Gamma(D_s^+ \to \phi\pi)} \\ &= \;\; 0.54 \pm 0.033 \pm 0.048 \\ &\frac{\Gamma(D^+ \to \overline{K^{*o}}\mu^+\nu)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} \\ &= \;\; 0.602 \pm 0.010 \pm 0.021 \end{aligned} \tag{64}$$

FOCUS also showed a world's best result[63] for

$$\frac{\Gamma(D^+ \to \overline{K^{*o}}\mu^+\nu)}{\Gamma(D^+ \to \bar{K^o}\mu^+\nu)} = 0.594 \pm 0.043 \pm 0.030. \tag{65}$$

This result bears on the issue of a claimed "missing" semileptonic rate.

9.4. FOCUS Results on $D^+, D_s \to \pi^+\pi^-\pi^+$ Decays and Multibody Charm Decays

FOCUS has carried out study of the Dalitz plot of the decay $D^+, D_s \to \pi^+\pi^-\pi^+$ using the K-Matrix formalism[64]. This has advantages over the so-called "isobar model" that adds together broad Breit-Wigner signals, usually with a flat background. The K-matrix is obtained from scattering data [67]. For the D_s^+ the dominant term is $(S-wave)\pi^+$ ($\sim$ 87%),about 10% $f_2(1270)\pi^+$, and about 7% $\rho^o(1450)\pi^+$. For the D^+ the dominant term is $(S-wave)\pi^+$ ($\sim$ 56%), about 12% $f_2(1270)\pi^+$, and about 32% $\rho^o(770)\pi^+$. This is the first time the K-matrix analysis has applied to a charm decay. The data are shown in Fig. 20

FOCUS also showed a variety of rare and unusual exclusive decay modes of charmed mesons.

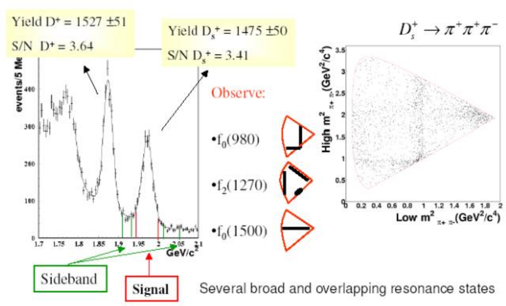

Figure 20. $\pi^+\pi^-\pi^+$ mass spectrum, showing both the D^+ and the D_s^+ (left side); Regions of the three pion Dalitz plot populated by various mass states (center); Dalitz plot for $D_s \to \pi^+\pi^-\pi^+$ (right side).

These included $D^o \to K^o\bar{K}^o$, $D^o \to K_sK_sK^+\pi^-$, $D^o \to K_sK_s\pi^\pm\pi^\mp$, and several other four, five, and six body decay modes of the D^o, D^+, and D_s. Several of these decay modes were seen for the first time and several were measured with much smaller uncertainties than previously. Resonant analyses of high multiplicity modes showed that most of the decays occur via two body resonant states[65].

9.5. FOCUS Results on Excited Charm Mesons

FOCUS presented new masses and widths for the narrow excited D mesons[66]. The mass spectrum has an excess that cannot be accounted for by known backgrounds. They speculate that it is associated with higher mass charmed mesons. FOCUS has fitted the excess as if it were a single broad resonance. It is possible that the excess is due to the "broad" $j = 1/2$ states.

9.6. First Results from CLEO-c

CESR has now concluded its B physics program and is running at various energies near the threshold for production of various pairs of charmed particles, initiallly at $D\bar{D}$ threshold. The storage ring has been augmented with a system of 12 wigglers to provide damping to increase the luminosity at these lower energies. The new, charm-oriented program is called CLEO-c[68]. In the spring and fall of 2003, approximately 18 million events were recorded at and around the $\psi(3770)$, resulting in a sample of 3 million tagged D decays. In 2005, the plan is to take about 3 fb^{-1} of data at $\sqrt{s}$ = 4140 MeV. In fall of '06, they will accumulate 1 fb^{-1} on the J/ψ, recording about 1 billion decays.

Some of the goals of running on the $\psi(3770)$ are to compare single and double tag events where a tag is achieved by reconstructing a D in one of the dominant and easily reconstructable decay modes: $D \to K^-\pi^+$ and $D \to K^-\pi^+\pi^+$. This permits one to measure the cross section and absolute branching fractions.

Figure 21 shows a single tag mass plot for the D^+ decay and the corresponding double tag signal. Running at threshold results in astoundingly clean signals and tagging permits one to do nearly background-free studies of exclusive and inclusive decays. It also provides the ability to measure the rate of $D^+ \to \mu^+\nu$ in singly tagged events. From this rate, one can extract the decay constant f_D:

$$\Gamma_{l\nu} = \frac{1}{8\pi}G_F^2 f_D m_l^2 M_D (1 - \frac{m_l^2}{M_D^2})|V_{cd}|^2. \qquad (66)$$

From the measured branching fractions and the known D^+ lifetime, f_D can be determined. Figure 22 shows the missing mass squared, MM^2, for tagged D events with only one additional muon of the correct sign for a purely leptonic decay. The left hand plot is the simulation and the right hand plot shows the data. There is a signal of 9 events over very low background at $MM^2 = 0$. Even from this small signal, the preliminary value of

$$f_D = 230 \pm 42 \pm 10 \text{ MeV} \qquad (67)$$

is already the best measurement of this quantity. This measurement can be compared with Lattice Gauge calculations and should provide an independent validation of them. This would increase the confidence with which LQCD could be used to extract CKM parameters in B decays.

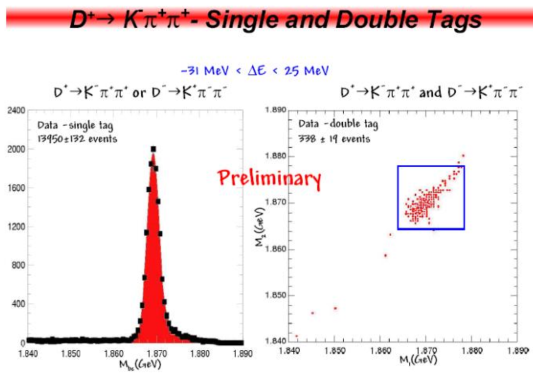

Figure 21. CLEO-c Single and Double Tag Distributions.

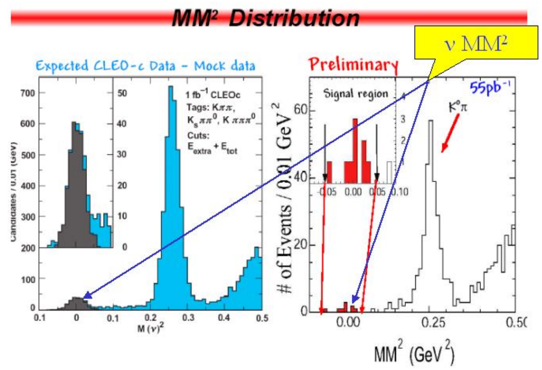

Figure 22. Simulation and data for $D^+ \to \mu^+\nu$ from CLEO-c running on the $\psi(3770)$. The sample is for single tagged events with only one additional muon. The distributions are for the "missing mass" squared, which is compatible with 0 when the only missing particle is the single neutrino characteristic of a fully leptonic decay.

It is evident that CLEO-c will be a marvellous source of information on charm particles. We look forward to their results over the next few years!

10. QCD AND PENTAQUARKS

10.1. Charmonium

Charmonium still presents us with significant challenges after 30 years. There remain what Chris Quigg described as the "lost tribes", states that still have not been observed. When new states, such as the $\psi(3872)$[69], are found, it is not always easy to settle on an interpretation. While the natural prejudice is that it is the $^3D_2$ $c\bar{c}$ state with $J^{PC} = 2^-$, there are problems with this interpretation. First, the mass is higher than the value of 3815 MeV/c^2 expected in potential models. Second, the dominant decay is expected to be a radiative decay but BELLE has measured:

$$\frac{\Gamma(X3872) \to \gamma\chi_{c1,2}}{\Gamma(X3872) \to \pi^+\pi^- J/\psi} < 0.89 \qquad (68)$$

Alternative interpretations include[70]:

- a $D\bar{D}^*$ cusp in the 1^{++} (S-wave);
- a deuteron-like "molecule" formed by π exchange between a D and a $\bar{D}$;
- a $c\bar{c}g$ hybrid state; or
- some other charmonium level.

Estia Eichten listed many inadequacies in our knowledge of mesons with one heavy quark and one light quark. This was clearly revealed in the bad miscalculation of the masses of the $D_s(0^+)$ and $D_s(1^+)$ states observed last year. These states were expected to broad but their low masses led to a kinematic suppression of their decays into allowed modes and resulted in very small widths.

Since potential models are inadequate, Eichten asserted that new degrees of freedom are required. He described an approach where (j=1/2) S and P waves can be viewed as a chiral supermultiplet and spontaneous chiral symmetry and HQS breaking can account for splitting within the supermultiplet.

10.2. Final results from Fermilab E835, A Study of Charmonium in $p\bar{p}$ Annihilations

Experiment 760 at Fermilab observed a structure in the process

$$p\bar{p} \rightarrow J/\psi\pi^o \quad (69)$$

at a mass of 3526.2±0.15±0.2 MeV/c^2. The width was less than 1.1 MeV/c^2 at 90% confidence level. They also observed that $\frac{Br(J/\psi\pi\pi)}{Br(J/\psi\pi^o)} < 0.018$ at 90% CL. This state was interpreted as the $^1P_1$ charmonium state, the h_c[71].

In the follow on run, E835, a preliminary analysis did not see this state and set an 90% CL upper limit on the cross section × branching ratio that was below the E760 result.

In the E835 run, however, they observed another signal, consisting of 23 events, for $\eta_c\gamma$ with a mass of

$$M = 3525.8 \pm 0.2 \quad (70)$$

(the systematic uncertainty is still being investigated). This state has properties that are a very good match to the expected values of the h_c.

10.3. Latest Results on the $\eta_c(2S)$

BELLE observed the $\eta_c(2S)$ in two different channels[72]:

$$\begin{aligned} B^\pm &\rightarrow K^\pm(\eta_c') \quad (71)\\ &\rightarrow K^\pm(K_sK^\pm\pi^\mp), \\ M &= 3654 \pm 6 \pm 8 \text{ MeV/c}^2 \end{aligned}$$

and

$$\begin{aligned} e^+e^- &\rightarrow J/\psi\eta_c', \quad (72)\\ M &= 3622 \pm 12 \text{ MeV/c}^2. \end{aligned}$$

CLEO[73] and BaBar[74] showed the production of this state from the two-photon fusion process. Although the consistency of the mass values leaves something to be desired, the multiple observations are viewed as clearing up the long-standing mystery concerning the $\eta_c(2S)$.

10.4. Observation of the $\Upsilon(1D)$ State of Bottomonium

The $\Upsilon(1D)$ state was observed in a beautiful and heroic analysis by CLEO[75] in the following four photon cascade:

$$\begin{aligned} &\Upsilon(3S) \quad (73)\\ &\rightarrow \gamma\chi(2P) \rightarrow \gamma\Upsilon(1D) \rightarrow \gamma\chi(1P) \rightarrow \gamma\Upsilon(1S) \end{aligned}$$

where $\Upsilon(1S) \rightarrow e^+e^-,\ \mu^+\mu^-$.

A total of 34.5±6.4 signal events were observed and the properties are consistent with the state being $\Upsilon(1^3D_2)$. The mass is

$$M(\Upsilon(1D)) = 10161.1 \pm 0.6 \pm 1.6 \text{ MeV/c}^2 \quad (74)$$

This mass is consistent with potential models and Lattice Gauge calculations.

10.5. The $D_s^*(2632)$

The SELEX Collaboration at Fermilab has reported evidence for a new, excited charmed-strange meson state[76]:

$$D_s^{+new}(2632) \rightarrow D_s^+\eta(\eta \rightarrow \gamma\gamma) \quad (75)$$

The data were taken with a 600 GeV/c Σ^- beam. SELEX had 554 D_s candidates. When they were combined with η's observed through their decay into two γ's, they obtained the invariant mass distribution shown in Fig. 23. There is a peak at 2635 MeV/c^2, with 42.5±9.5 events over a background of 54.4±2.5. The statistical significance of the peak is claimed to be 6.3σ. The mass is

$$2635.9 \pm 2.9 \text{ MeV/c}^2. \quad (76)$$

The width is consistent with the resolution, as determined from their Monte Carlo. The background shape has attracted some discussion. The background is determined by combining D_s sidebands with real η candidates; D_s candidates with η sidebands; and real η candidates from one event with real D_s candidates from another event. All methods produce a flat background, which is what they use in their fit.

SELEX also observed this state in the D^oK^+ decay mode. The mass is consistent with the value from the $D_s\eta$ mode. The width is consistent with the Monte Carlo resolution of 4.9 MeV/c^2. From this, they establish that $\Gamma < 17$ MeV/c^2.

This state has some unusual characteristics. First, 55% of the total SELEX sample of ~550 D_s's must be daughters of decays from this state. Second, the charge asymmetry is

$$\frac{D_s^+(2632) - D_s^-(2632)}{D_s^+(2632) + D_s^-(2632)} \sim 0.4. \quad (77)$$

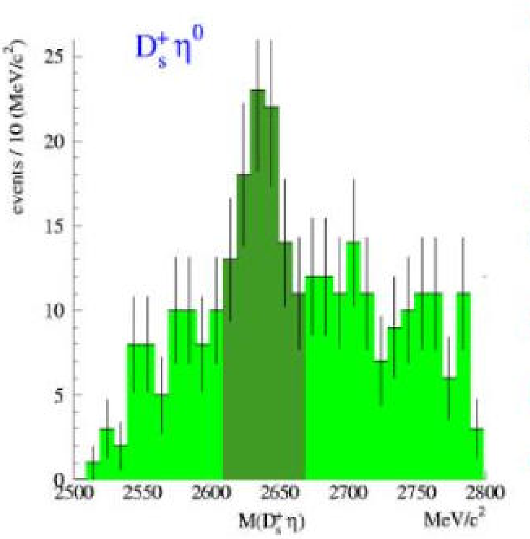

Figure 23. Invariant mass distribution for $D_s\eta$ showing a peak at 2632 MeV/c^2.

This is very similar to other charm-anti-charm production asymmetries. This means that at least 1/5 of the events are anti-correlated to the strangeness of the beam particle. This all argues for production by normal fragmentation processes. Thus, any experiment with a large sample of D_s's and an η reconstruction capability should see copious production of this state. Similarly, many experiments can detect the D^oK^+ mode with high efficiency. Confirmation or the opposite should be swift.

10.6. Excited B mesons and Baryons

LEP experiments continue to search for B^{**} states and B-baryons. The crucial issue is the treatment of the background. Inadequate understanding of the background can lead to instabilities in the signals, falsely high production rates, and shifted mass peaks.

There are new measurements of B^{**}_{ud} from DELPHI. The production rate is

$$\frac{\sigma(B^{**}_{u,d})}{\sigma(b)} = 0.157 \pm 0.011 \pm 0.029. \qquad (78)$$

The masses for the two narrow (j=3/2) states are:

$$\begin{aligned} M(B_2^*) &= 5738 \pm 14 \text{ MeV/c}^2 \\ M(B_1) &= 5732 \pm 20 \text{ MeV/c}^2 \end{aligned} \qquad (79)$$

They also searched for $B_s^{**} \to B^{(*)+}K^-$. They have a signal at the 3.8σ level. The mass is

$$M(B^*_{s2}) = 5852 \pm 5 \text{ MeV/c}^2 \qquad (80)$$

The production rate is

$$\frac{\sigma(B^*_{s2})}{\sigma(b)} = 0.0093 \pm 0.0020 \pm 0.0013 \qquad (81)$$

The B^*_{s1} is not seen - a bit of a mystery.

Finally, DELPHI searched for $\Sigma_b^{\pm(*)} \to \Lambda_b\pi^\pm$ but did not see a signal. The limit on the production rate is

$$\frac{\sigma(\Sigma_{b^*})}{\sigma(b)} < 0.012 \text{ 90\% CL} \qquad (82)$$

10.7. Pentaquarks: Is they is, or is they ain't?

The conference had a special session devoted to pentaquarks. "Ordinary hadrons" are mesons consisting of quark-antiquark combinations and baryons consisting of three quarks. Other possible combinations are multiquark mesons, such as $q_1\bar{q}_2q_3\bar{q}_4$, glueballs, and hybrids, combinations of quarks and gluons. Pentaquarks are the baryonic analog of multiquark mesons and consist of $q_1q_2q_3(q_4\bar{q}_5)$. Pentaquarks may have exotic quantum numbers, that is quantum numbers that cannot be constructed from 3 quarks. For example, the state $uud(\bar{s}d)$ is a baryon with strangeness +1, whereas all normal baryons have negative strangeness. Historically, there have been several candidates for these unusual states. Some have been firmly established but their identification as a multiquark state or a gluonic state have not been proven. Other states, ones with exotic quantum numbers, have generally not stood the test of time and experiment. Theory does not provide particularly crisp guidance concerning the mass spectrum, widths or relative branching fractions of these states. Production mechanisms are also a mystery. All this is by way of saying that this area is in a state of confusion!

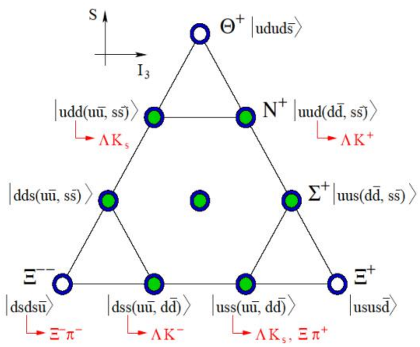

Figure 24. Anti-decuplet of pentaquarks.

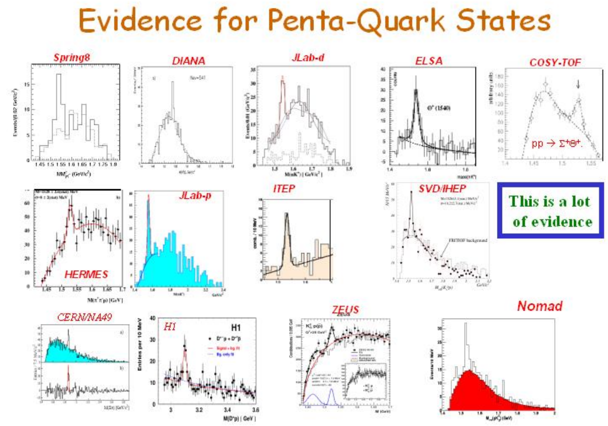

Figure 25. Thirteen signals for the Θ^+.

The recent interest in pentaquarks was stimulated by theoretical work[77]. A proposed anti-decuplet of pentaquarks is shown in Fig. 24. There are also many other states involving charm and bottom quarks.

Recently, several groups have reported observations of a pentaquark candidate, called the Θ^+. It is seen in two decay modes:

$$\Theta^+ \to K^+ n, pK_s \tag{83}$$

at a mass of about 1540 MeV/c^2. The width is very small, below a few MeV/c^2. The first decay mode has $S = +1$, which makes this state an exotic baryon. The second decay mode has indeterminate strangeness. The decay mode pK^+ is not seen so the state is most likely an $I = 0$ state.

The evidence for the Θ^+ is shown in Fig. 25[78]. With these many observations, one would expect the state to be well-established. However, this is not the case because

- no single experiment is statistically compelling;
- some of the analyses have unusual cuts;
- it is possible for reflections from known resonances or kinematic effects to mimic signals[79];
- the masses are not the same in all the results; and
- several groups that might have expected to see signals have not seen them.

This skepticism is in part based on past experience. Signals such as these have been claimed and then eventually have been shown to be incorrect. Some of the groups that are reporting signals are relatively new to this kind of multiparticle spectroscopy and may not be aware of all the pitfalls in this kind of analysis. At this conference, we had participants from groups that had seen signals, as well as from groups that had failed to observe signals. We had a "lively interchange!"

One cause for skepticism is the inconsistency of the mass values of the various observations. The results cluster into two groups separated by around 12 MeV/c^2. Another cause for skepticism comes from the very small width of the $\Theta(1540)^+$. It is at most a few MeV/c^2[80]. This is surprising for such a heavy state.

Many of these issues are illustratrated by examining the positive result from CLAS, a photoproduction experiment at Jefferson Lab[81]. Their signal for $\Theta(1540)^+ \to K^+ n$ is shown in Fig. 26. Signals for the Θ are observed on both deuterium and hydrogen targets. The production mecha-

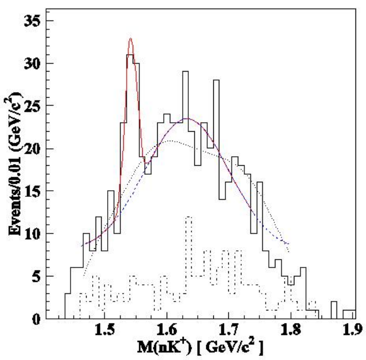

Figure 26. The nK^+ invariant mass spectrum from CLAS.

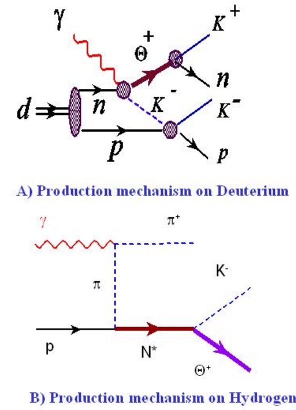

Figure 27. Photoproduction mechanisms for the Θ^+ in CLAS. A) is for production on Deuterium; and B) is for production on Hydrogen.

nism is not established. Figure 27 shows possible production mechanisms, which have to be different for deuterium targets and hydrogen targets in CLAS. There are possible reflections from known resonances that can contribute to the pK^+K^-n final state. These include

$$\begin{aligned} \gamma d &\rightarrow \phi p(n),\ \phi \rightarrow K^+K^- \quad (84) \\ \gamma d &\rightarrow \Lambda(1520)K + (n), \Lambda(1520) \rightarrow pK^- \end{aligned}$$

In these reactions, the neutron is a spectator and is not likely to mimic a neutron from the Θ. Cuts are placed on the K^+K^- mass and the pK^- mass to eliminate any problems.

Generally speaking, once well above threshold for production, a particle is produced abundantly. Therefore, pentaquarks should be produced in most particle physics experiments and nearly all high energy experiments have carried out analyses to look for them. Most experiments have looked for the pK_s decay mode since that is relatively easy experimentally. ALEPH, DELPHI,and L3 at LEP have looked for $e^+e^- \rightarrow e^+e^-\Theta X$ and have not observed a signal. BaBar also has a null result. HERA-B, CDF, BES, STAR, ALEPH, OPAL,DELPHI, PHENIX, and NA49 have looked and also not seen a signal.

While many of the experiments that see a signal are relatively low energy experiments, both HERMES and ZEUS at HERA also report signals. One interesting observation was that the "relative production" (based on a normalization to the number of observed $K_s \rightarrow \pi^+\pi^-$) is a factor of 35 higher in HERMES, which is at low energy, than at ZEUS, which is at much higher energy. This suggests, but does not prove, that it may be hard to make a pentaquark at high energy, where it must emerge as a fragmentation product, than at low energy, where the phase space is restricted. While this argument could account for the pattern of observation and non-observation, such arguments invoking special dynamics are, in the author's experience, usually wrong.

Various mechanisms have been proposed for generating a false signal. One is that this is a manifestation of the Deck Effect, which produces threshold enhancements that are not resonances but may look like them. Usually, this produces relatively broad structures so I don't take this explanation too seriously. Another is that the signal is manufactured by treating neutral Vee's that are actually Λ's as K_s's and then perhaps having the proton appear again as a "ghost track" to provide both a K_s and a proton. This kind of conspiracy can cause fake signals but can easily be elimnated by removing K_s's that are also consistent with being Λ's. The groups that claim to have K_sp signals should check for this if they haven't already. If they have, they should say so!

The family of pentaquark states is large and searches have been conducted for other members. There have been claimed observations of other exotic states: $\Xi(1862)^{--} \to \Xi^-\pi^-$ by the NA49 Collaboration [82] and the $\Theta_c^o(3100) \to D^{*-}p, D^-p$ by the H1 Collaboration [83]. These signals are also disputed by other experiments.

Meanwhile, followup experiments are being planned to settle ths issue. While we wait for new results, proponents of the Θ should listen to all criticisms and address them. They should study and improve the treatment of backgrounds in their fits. And they should try to justify all their analysis cuts and demonstrate the stability of the signals with respect to the cut values. Eventually, more data will become available and the truth will emerge. We should be patient.

11. CONCLUDING REMARKS

I am overwhelmed by the quality and quantity of the work presented at this conference. Committment to hard work and willingness to challenge established results and the "accepted ways" of doing things does pay off and will be crucial if we are to succeed in overthrowing the tyranny of the Standard Model and in addressing the many mysteries that it does not explain. Recently, we have had many surprises in heavy quark physics, the sign of a vibrant area of research. You are all to be congratulated!

It is true, however, that with all these new results and some surprises, we have not seen definitive evidence for new physics in heavy quarks. The Standard Model survives. Yet, I feel that we will soon see, and perhaps may even have already begun to see, the first cracks.

But, I warn you that I am an optimist. I am a lifelong baseball fan and have lived half my life in Boston and half in Chicago. I root for the Red Sox, White Sox, and Cubs to increase my chances. Someday, one of them will win the World Series and all the years of frustration will have been worth it[84]. Meanwhile, there is always hope because there is always next season!

Similarly, one day an experiment will defeat the Standard Model. After all the work, it will have been worth it and think how happy we will be and how much we will stand to learn. Meanwhile, there is always the next year's data and the next conference. We'll see you all in Lancaster!

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84. Note added well after talk but before submission of paper: I now have experimental verification that this statement is true!